Asian Journal of Coaching Science
Vol. 2, No. 1, 25-34 (December, 2018)
DOI:10.29426/ajcs.201812_2(1).0003

Effect of Hyperoxia and Cooling Application in High Intensity Interval Rowing Training

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Received: January, 2019
Accepted: March, 2019

Abstract

The purpose of this research is to investigate the effect of cooling and hyperoxia application on the circulatory and metabolism system during rest period of high intensity interval training (HIIT). This research included six healthy male participants (age 23.00 ± 2.02 years) who completed two high intensity interval rowing training session with cooling or hyperoxia application in counterbalance order. The HIIT contained 2 × 2 × 300 m of rowing. The rest period between sets was 10 min and the rest between every 300 m rowing in each sets was 90 s. The intensity was set to 95% of individual maximal power output (376.33 ± 136.72 watt). During the 10 min rest, either 2 × 90 s cooling (-120–-140°C) or 8 min hyperoxia air (80% O_2) were applied. Capillary blood lactate (La), heart rate (HR), blood ammonia (NH_3), rating of perceived exertion (RPE), and venous blood gas (pO_2, pCO_2, pH, HCO_3, and sO_2) were measured. The results showed that the concentration of blood lactate after HIIT was higher in hyperoxia than in cooling application ($p > .05$). During the 10 min rest between training sets, ammonia increased more in cooling application than in hyperoxia ($p < .05$). pO_2 and sO_2 at R8 were higher in hyperoxia than in cooling application. In addition, HCO_3 at R8 is lower in hyperoxia. In conclusion, hyperoxia application helps to regulate heart pressure,

increase partial pressure of oxygen and oxygen saturation, and delay lactic acid and blood ammonia concentration in the subsequent exercise, while cooling contributes to excluding lactic acid in recovery period.

Keywords: hyperoxia, cooling, high intensity interval training (HIIT), recovery

Introduction

The results of sport science research have changed the mode of training in recent years, and have increased the exercise load continuingly. Most research has showed that high intensity interval training (HIIT) could produce the effect as same as long term training (Banfi, Lombardi, Colombini, & Melegati, 2010; Bleakley, Bieuzen, Davison, & Costello, 2014; Costello et al., 2015; González-Alonso & Calbet, 2003; Hausswirth et al., 2013; Pournot et al., 2011; Zalewski et al., 2014). However, the muscle inflammation would be made by muscle contraction under high and anaerobic load. Furthermore, the lactic acid made from anaerobic glycolysis system would also be the pressure to the body. Therefore, to inhibit the anaerobic symptom, hyperoxia and cooling were applied on sports training gradually. Absorbing hyperoxia could increase the percentage of combining oxygen and erythrocytes, and reduce the hypoxia symptoms through circulatory system. The hyperoxia could not only be applied on sports injuries and recovery, but also on sports training and enhance the training effect. The study related to sports training has said that absorbing hyperoxia during exercise could reduce the anaerobic symptom in muscle tissue (Rost & Hollmann, 1982). Jang (2003) took six athletes of 400-m race as subjects to do the HIIT experiment (3 × 5 × 200 m), the intensity was 95% of personal best speed, and the hyperoxia (97%) was applied during the rest period (10 min). This study found that the lactate concentration and heart rate at Set-3 were equal to Set-1, subjects' fatigue was not accumulated. Huang, Lee, and Jang (2008) found that absorbing hyperoxia before, between and after HIIT was help for producing less lactate acid during exercise and excluding lactate acid in recovery period, and also increased sO_2. Tucker et al. (2007) took 11 males as subjects to do twice 20 km time trial, and they found applying hyperoxia can rise performance for 5% and keep the output power. The physiological changes after training, such as the number of mitochondria, capillary density in skeletal muscle, and alveolar gas exchange, would limit the anaerobic symptom of muscles during exercises (Heck & Schulz, 2002). Therefore, training with hyperoxia would make up the impact of these factors.

Cooling had been applied on sports for some time, from iced water immersing and ice compression in the early to cryotherapy in modern. Cryotherapy uses the extremely cold nitrogen to touch skin directly, and leads to vasoconstriction and makes the blood flow into the deeper blood vessels. After returning to the normal temperature, capillaries will extent and accelerate the blood flow. Cooling was often used on sports injury in the past; nevertheless, it was used in the recovery gradually in the recent years, and even in sports training. The study about cryotherapy can be divided into before exercises, interval and the recovery period. It is

said that cooling before exercise (pre-cooling) could reduce the pressure on working muscle in the hot environment, and improve the endurance obviously (Wegmann et al., 2012). Johnson (2005) found that cooling before exercise can delay the increase of core temperature and reduce pressure, also make subjects have greater strength and to complete 1,500 m rowing test with less time. Krüger, de Marees, Dittmar, Sperlich, and Mester (2015) indicated that cooling at interval (inter-cooling) was able to rise the oxygen content in the max effort exercise and reduce the oxygen consumption and heart rate. Santos et al. (2012) took nine Brazilian jiu-jitsu fighters as subjects and applied cryotherapy after twice 90 min training (post-cooling) in crossover design. It was found that cryotherapy can make serum creatine phosphokinase (CPK), lactate dehydrogenase (LDH), and hypoalgesia lower, and also keep the better isometric strength endurance. From these research, we find that no matter cryotherapy was applied before exercises, interval, or recovery period, it all can make positive effect on physiological regulation.

With the studies above and the improvement of technology, the possibility of applying hyperoxia and cooling in training and competition increases; however under the limit resource, understanding the advantages and disadvantages of all kinds of recovery strategies will maximize the effectiveness. To sum up, this study will investigate the effect of cooling and hyperoxia application on the circulatory and metabolism system in high intensity interval rowing.

Methods

The subjects were six healthy students, the average age was 23.00 ± 2.02 years old, 172.00 ± 2.53 cm in height, 65.00 ± 3.24 kg in weight, and the average max output power of rowing was 446.00 ± 169.01 watt (Table 1).

The experiment lasted for four days, and the processes in turn were intensity deciding test, two days of training with one day rest in between (Figure 1). The experiment used rowing ergometer (Model D, Concept2, Morrisville, VT, USA) as the experiment equipment. The intensity deciding test was to complete a 500 m rowing in subjects' effort and the personal max output power would decide subjects' experiment order. The exercise load of two days training

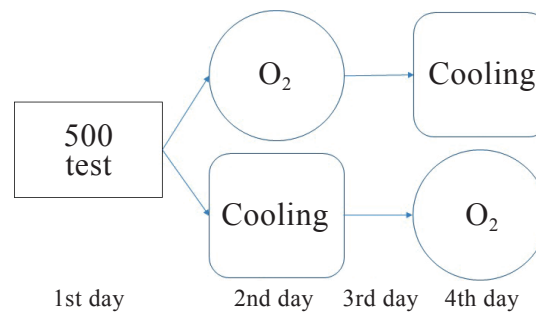

Figure 1. Experimental procedure.

Table 1
Subject Characteristics (M ± SD)

Item	Subject characteristics
Old (yr)	23.00 ± 2.02
Height (cm)	172.00 ± 2.53
Weight (kg)	65.00 ± 3.24
Max output power ($watt_{max}$)	446.00 ± 169.01

was 2 × 2 × 300 m, 90 s recoveries between the reps, and 10 min rest between the sets. The resistance of rowing ergometer was set as level-5, and the intensity was the 95% of the personal max output power. The hyperoxia (the concentration was set at 80%) and cooling (the temperature was set from -120°C to -140°C) were applied in the 10 min between the sets. Hyperoxia (Newlife Intensity, AirSep, Buffalo, NY, USA) was absorbed with the oxygen mask right away after Set-1 and last for 8 min. Cooling (Cryosauna, Space Cabin, Kherson, Ukraine) was used for twice (90 s/time), and rest 3 min in between. In order to make skin touch the cold air as much as possible, males were asked to bare the upper body and legs, while females just bare legs. In addition, for the safety, subjects had to wear socks to cover the sensitive parts and were not allowed to wear metallic accessories. The counterbalance was used to decide subjects' experiment order, and the tests were separated for 24 hr (Figure 2). The biological parameter measured include lactate (La), ammonia (NH_3), venous blood gas (pO_2, pCO_2, pH, HCO_3, and sO_2), heart rate, and Borg Rating of Perceived Exertion (RPE) Scale. The venous blood gas was measured by drawing blood (100 mmol/L) from fingertips, and inserted into the cartridge. The results appeared after inserting the cartridge into the blood analyzer (i-STAT Handheld, Abbott Point of Care Inc., Princeton, NJ, USA) for 3 min.

All data in the experiment was presented as mean and standard deviations, and analyzed the parameter by correlated samples *t*-test. The graphs were created through SigmaPlot 14.0. The significance level was set at $\alpha = .05$.

Results

The experiment results showed that the mean value at R8–Set-1 of blood lactate after

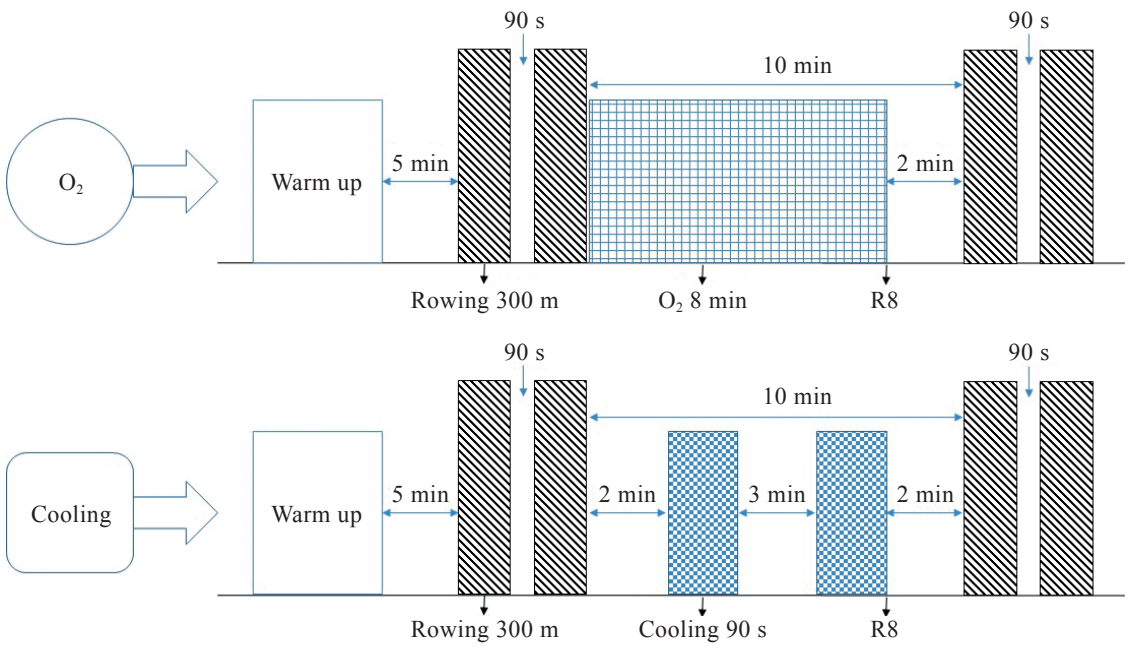

Figure 2. High intensity interval training (HIIT) applied with hyperoxia and cooling.

HIIT applied with hyperoxia and cooling were 1.70 ± 2.01 mmol/L and 0.16 ± 1.57 mmol/L respectively, and the difference was not significant ($p > .05$); the average value at Set-2–R8 were 1.17 ± 1.26 mmol/L and 3.36 ± 2.50 mmol/L respectively, and the difference was not significant ($p > .05$). For the heart rate, the average value of Set-2–Set-1 was -1.50 ± 5.25 min^{-1}, and the other was 0.83 ± 6.67 min^{-1}, and there was no significant difference ($p > .05$). The concentration of blood ammonia at R8–Set-1 was -3.33 ± 40.12 mmol/L in hyperoxia and was 22.00 ± 23.07 mmol/L in cooling, also with no significant difference ($p > .05$). For the blood gas, hyperoxia and cooling were significantly different for oxygen partial pressure and oxygen saturation at R8 ($p > .05$), but not for carbon dioxide partial pressure, pH and HCO_3 ($p > .05$). The RPE scale also showed no difference ($p > .05$) (Table 2).

Discussion

The Effect of Cooling and Hyperoxia Application on the Circulatory

There was an obvious difference on the heart rate of the subsequent exercise between hyperoxia and cooling. According to the results, after absorbing hyperoxia and cooling, compare the heart rate of Set-2 to Set-1, cooling had raise 0.83 min^{-1}, but hyperoxia reduce 1.50 min^{-1}. It indicated that hyperoxia was more efficient to regulate heart pressure (Kilding, Wood, Sequira, & Bonetti, 2012; Nummela, Hämäläinen, & Rusko, 2002; Ploutz-Snyder, Simoneau, Gilders, Staron, & Hagerman, 1996). Ulrich et al. (2017) asserted that hyperoxia applied on the progressive ramp exercise or constant-load bicycle exercise can both improve the performance, the effects included enhancing pulmonary gas exchange, reducing ventilatory work and heart rate, and also increasing sO_2. Wang (2018) found that absorbing hyperoxia after HIIT (4 × 90 s) can improve heart rate apparently better than cooling. These factors of the ability of transporting oxygen to muscles, the speed of oxygen diffusing from capillary to cells, and the utilization rate of oxygen in muscles would influent the sport performance, and higher intensity would limit the supply of oxygen. Under the hyperoxia condition, the sO_2 would increase and reduce the ventilatory equivalent for O_2 and CO_2, and then reduce the heart rate. In the part of the blood gas, cooling and hyperoxia could both produce the positive effect of enhancing pO_2 and sO_2, and reducing pCO_2 and HCO_3. Compared the hyperoxia with cooling, the effect of hyperoxia was better because it increased pO_2 for 45.30 mmHg and sO_2 for 6%, but cooling could only increase pO_2 for 4.16 mmHg and did not change sO_2. It was reported that respiratory exchange ratio can be decrease by absorbing hyperoxia (Favier et al., 2005; Helgerud et al., 2010; Kaijser, 1970; Ploutz-Snyder et al., 1996), and hyperoxia applied after training can enhance sO_2 (Haseler Haseler, Hogan, & Richardson, 1999; Kilding et al., 2012; Peeling, & Andersson, 2011). As a result, both hyperoxia and cooling could have positive effect on the circulatory. But compared to cooling, the effect of absorbing hyperoxia on reducing heart rate, increasing pO_2 and sO_2 was better.

The Effect of Cooling and Hyperoxia Application on the Metabolism System

The lactate concentration of cooling was always lower than hyperoxia no matter what time it was. However, compared the difference

Table 2
Biological Data (M ± SD)

Bio	Set-1	R8	Set-2	R8–Set-1	Set-2–R8	Set-2–Set-1
			O_2			
La (mmol/L)	14.28 ± 1.20	15.97 ± 2.18	17.15 ± 1.38	1.70 ± 2.01	1.17 ± 1.26	
HR (min^{-1})	185.00 ± 8.35		183.50 ± 6.55			-1.50 ± 5.25
NH_3 (mmol/L)	153.00 ± 36.68	149.67 ± 13.82		-3.33 ± 40.12		
pO_2 (mmHg)	75.20 ± 5.74	120.50 ± 15.84*				
pCO_2 (mmHg)	34.94 ± 4.39	29.28 ± 1.87				
pH	7.21 ± 0.05	7.15 ± 0.04				
sO_2	0.91 ± 0.02	0.97 ± 0.01*				
HCO_3 (mmol/L)	13.80 ± 1.35	10.10 ± 0.83				
RPE	19.33 ± 0.47		19.50 ± 0.76			0.17 ± 0.69
			Cooling			
La (mmol/L)	13.82 ± 2.69	13.98 ± 2.24	17.35 ± 4.60	0.16 ± 1.57	3.36 ± 2.50	
HR (min^{-1})	180.33 ± 4.42		181.17 ± 6.26			0.83 ± 6.67
NH_3 (mmol/L)	128.67 ± 24.72	150.67 ± 19.02		22.00 ± 23.07		
pO_2 (mmHg)	73.67 ± 2.98	77.83 ± 6.94				
pCO_2 (mmHg)	37.87 ± 3.51	34.00 ± 2.73				
pH	7.21 ± 0.06	7.15 ± 0.06				
sO_2	0.91 ± 0.02	0.91 ± 0.02				
HCO_3 (mmol/L)	15.15 ± 1.34	12.43 ± 2.03				
RPE	19.00 ± 0.58		19.50 ± 0.50			0.50 ± 0.50

Note. La = capillary blood lactate; HR = heart rate; RPE = rating of perceived exertion. La [R8–Set-1]: $t(5) = 1.64$, $p = .16$; La [Set-2–R8]: $t(5) = -1.36$, $p = .23$; HR [Set-2–Set-1]: $t(5) = -1.05$, $p = .34$; NH_3 [R8–Set-1]: $p = .69$; pO_2 [R8]: $t(3) = 6.38$, $p < .01$; pCO_2 [R8]: $p = .13$; pH [R8]: $t(3) = 0.49$, $p = .66$; sO_2 [R8]: $t(3) = 7.83$, $p < .01$; HCO_3 [R8]: $t(3) = -1.54$, $p = .22$; RPE [Set-2–Set-1]: $p = .50$.
*$p < .05$.

of R8 to Set-1 and Set-2 to R8, it was found that hyperoxia can delay the lactate accumulating in the rest period and the subsequent exercise more, while cooling can exclude the lactate faster in the recovery period. After cooling and absorbing hyperoxia in the rest period, the lactate concentration at R8 of the former increase 0.16 mmol/L, and the latter was 1.70 mmol/L; after the subsequent exercise, the lactate concentration at Set-2 of the former increase 3.36 mmol/L, and the latter was 1.17 mmol/L. The results above showed that hyperoxia could delay the lactate accumulating in the rest period and the subsequent exercise. Stellingwerff, LeBlanc, Hollidge, Heigenhauser and Spriet (2006) took seven active males as subjects, and did a 40 min cycle test at 70% $\dot{V}O_{2peak}$ with breathing 21% or 60% O_2 randomly. The study found that hyperoxia decreased the pyruvate production, and also

significantly decreased lactate accumulation and total lactate production (60%: 22.6 ± 6.4 mmol/L vs. 21%: 31.3 ± 8.7 mmol/L). For the lactate concentration of recovery, there was no difference between hyperoxia and cooling after the exercise for the 1st minute (E1). But at the subsequent recovery, the lactate concentration of cooling was obviously lower than hyperoxia (Figure 3). Especially at E5 and E7 of recovery, the differences of lactate concentration were 1.42 mmol/L and 1.31 mmol/L respectively. The contraction and relaxation of capillary caused by cooling helped excluding the metabolic substances such as lactic acid, ammonia, and was helpful to recovery. The body surface temperature would reduce after cooling, and exercising would make it increase. The human body had to thermoregulate constantly in order to keep in normal temperature, so the vasoconstriction on skin surface would happened, which caused blood flow velocity faster, reduce the production of lactate, and enhance excluding lactate. Kay, Taaffe and Marino (1999) also found that the lactate concentration at E5 to E20 of recovery was significantly lower than control group, and it demonstrated that cooling helped delaying lactate accumulation and enhancing substance metabolizing. The effect of hyperoxia and cooling on ammonia concentration was different obviously. The ammonia concentration at Set-1 before hyperoxia was 153 mmol/L, and it reduced 3 mmol/L after breathing hyperoxia, but it increased 22 mmol/L with cooling. Wang, Smith, and Jang (2009) took six athletes of 400-m race as subjects to do the three day training

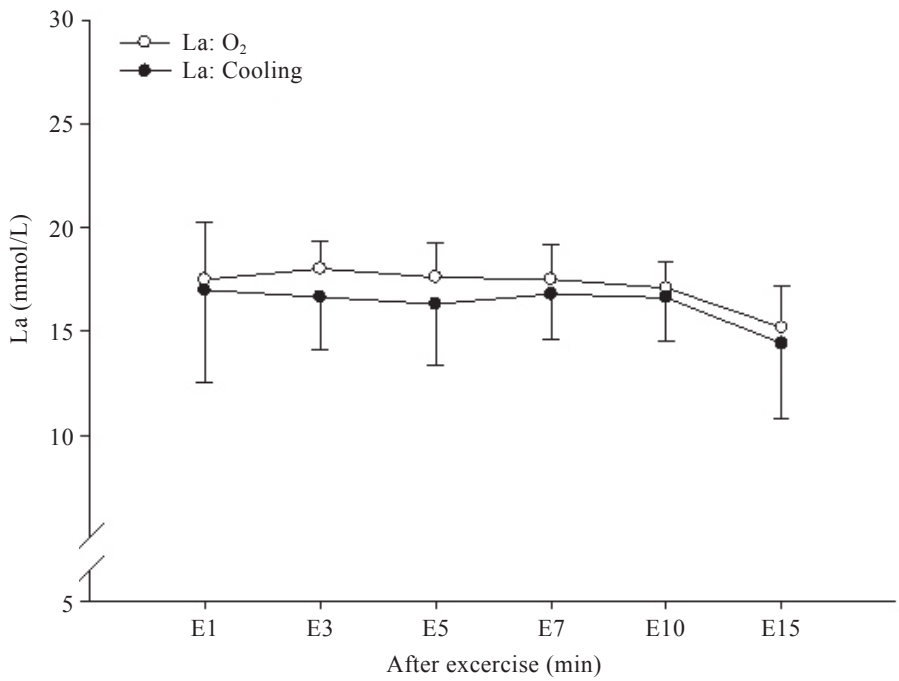

Figure 3. The lactate curve in recovery period.

Note. La = capillary blood lactate. E1: $t(5) = -0.0964$, $p = .927$; E3: $t(5) = 1.090$, $p = .325$; E5: $t(5) = 1.176$, $p = .292$; E7: $t(5) = .797$, $p = .461$; E10: $t(5) = 0.252$, $p = .811$; E15: $t(5) = 0.459$, $p = .666$.

in hyperoxia conditions. The first and third day was HIIT (3 × 3 × 20 sec, 90%), and the second day was constant-load running. The result of the research was that the ammonia concentration at 2nd set of 1st and 3rd day decreased significantly. The previous study indicated that hyperoxia helped decreasing ammonia faster than cooling while applying hyperoxia and cooling at interval (Wang, 2018). Van Wenum et al. (2018) indicated that hyperoxia was able to differentiate HepaRG and C3A more. To sum up, for the metabolism system, hyperoxia helped delaying lactate and ammonia accumulation of the rest period and the subsequent exercise, while cooling was benefit for excluding lactate in the recovery period after exercise.

Conclusions

Both hyperoxia and cooling could have positive effect on circulatory, and hyperoxia was more effective in reducing heart rate and increasing pO_2 and sO_2 than cooling. In addition, hyperoxia was also beneficial to delay lactate and ammonia accumulation of the rest period and the subsequent exercise, and cooling helped excluding lactate after exercise. Applying hyperoxia and cooling duly would contribute to regulate the pressure during exercises and accelerate the recovery.

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